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PAIR (AN/SQQ-23) COMPENSATION FOR OWN SHIP'S MOTION ON THE SEAR--ETC(U)
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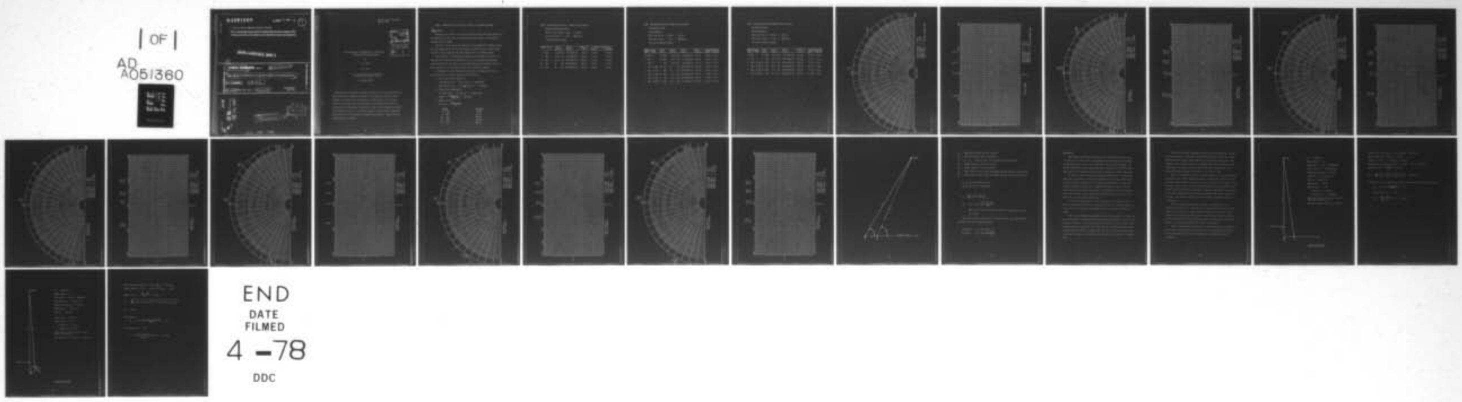

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U. S. NAVY ELECTRONICS LABORATORY, SAN DIEGO, CALIFORNIA

This is a working paper giving tentative information about some work in progress at NEL. If cited in the literature the information is to be identified as tentative and unpublished.

NEL/Technical Memorandum 1074

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PAIR (AN/SQQ-23) COMPENSATION FOR OWN SHIP'S MOTION ON THE SEARCH DISPLAY

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J. G. Lamb (NEL Code 2140)

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NEL Technical Memorandum
Number 1074

PAIR (AN/SQQ-23) COMPENSATION FOR OWN SHIP's MOTION ON THE SEARCH DISPLAY

by

J. G. Lamb

Code 2140

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San Diego, California 92152

11 January 1966

This technical memorandum represents a portion of the work being done on NEL Problem J714, AN/SQS-23 Performance and Integration Retrofit (PAIR) Program. It should not be construed as a formal report as its primary intent is to present some of the problems confronting project personnel and some of the preliminary conclusions. While it was originally published in a different form, it is now being included in the technical memorandum series for sake of documentation uniformity and control. Limited outside distribution is intended.

PAIR: Compensation for Own Ship's Motion on the Search Display

INTRODUCTION

Retention and display of echo return history allows the sonar operator to see what areas of the ocean consistently send back echoes, indicating the probability of a target.

Own ship's motion causes the returns to be displayed at different points as time progresses and the echo indications associated with a single target may be so widely separated that the operator fails to correlate them.

The combination of moderate ship speeds, in the order of 15 knots, and long periods between pulse transmissions as in the proposed non-alerting search-track modes may cause a five period history to be dispersed over 8 or more range bins or 4 bearing bins even with a stationary target.

Investigation of the results and feasibility of compensation for own ship's motion on the search display seems justified.

1. Echo return time computation:

   If sound velocity = 4800 ft/sec = 1600 yd/sec

   Echo return time $= 2 \times \frac{1}{1600}$ sec/yd = 1.25 ms/yd

2. Ships motion computation:

   If ships speed = 15 knots/hr = 30,000 yd/hr

   Motion $= \frac{30{,}000 \text{ yd}}{3{,}600 \text{ sec}} = 8\frac{1}{3}$ yd/sec

3. Range bin size:

   Bin size $= \frac{\text{Range Scale}}{48}$

Scale	Bin Size
2.5 Kyd	52 yd
5 Kyd	104 yd
10 Kyd	208 yd
20 Kyd	416 yd
40 Kyd	832 yd

PAIR: Uncompensated Motion - Range Scale Relations

Simple transmission modes

Echo time per yard of range = 1.25 ms

Own ship's speed = 15 kt = $8\frac{1}{3}$ yd/sec.

5 period memory display

Search Scale	Trans. Period	Ships Motion	Range Bin Size	5 Period Dispersion Range	Bearing
2.5 Kyd	3.125 sec.	26 yd/period	52 yd	3 bins	2 bins
5 Kyd	6.25 sec.	52 yd/period	104 yd	3 bins	2 bins
10 Kyd	12.5 sec.	104 yd/period	208 yd	3 bins	2 bins
20 Kyd	25 sec.	208 yd/period	416 yd	3 bins	2 bins
40 Kyd	50 sec.	416 yd/period	832 yd	3 bins	2 bins

PAIR: Uncompensated Motion-Range Scale Relations

Non-alerting modes

Dual frequency

Echo time per yd. of range = 1.25 ms

Own ship's speed = 15 kt. = $8\frac{1}{3}$ yd/sec.

Five period memory display

Search Scale OMNI	RDT	Track Scale	Trans. Period	Ship's Motion	Range Bin Size	5 Period Spread Range	Bearing
2.5 Kyd	0	2.5 Kyd	3.125 sec.	26 yd/period	52 yd.	3 bins	2 bins
5 Kyd	0	2.5 Kyd	6.25 sec.	52 yd/period	104 yd.	3 bins	2 bins
5 Kyd	0	5 Kyd	6.25 sec.	52 yd/period	104 yd.	3 bins	2 bins
4 Kyd	10 Kyd	2.5 Kyd	25 sec.	208 yd/period	208 yd.	5 bins	3 bins
4 Kyd	10 Kyd	5 Kyd	25 sec.	208 yd/period	208 yd.	5 bins	3 bins
4 Kyd	20 Kyd	2.5 Kyd	37.5 sec.	312 yd/period	416 yd.	4 bins	2 bins
4 Kyd	20 Kyd	5 Kyd	37.5 sec.	312 yd/period	416 yd.	4 bins	2 bins
4 Kyd	20 Kyd	10 Kyd	37.5 sec.	312 yd/period	416 yd.	4 bins	2 bins

PAIR: Uncompensated Motion-Range Scale Relations

Non-alerting modes

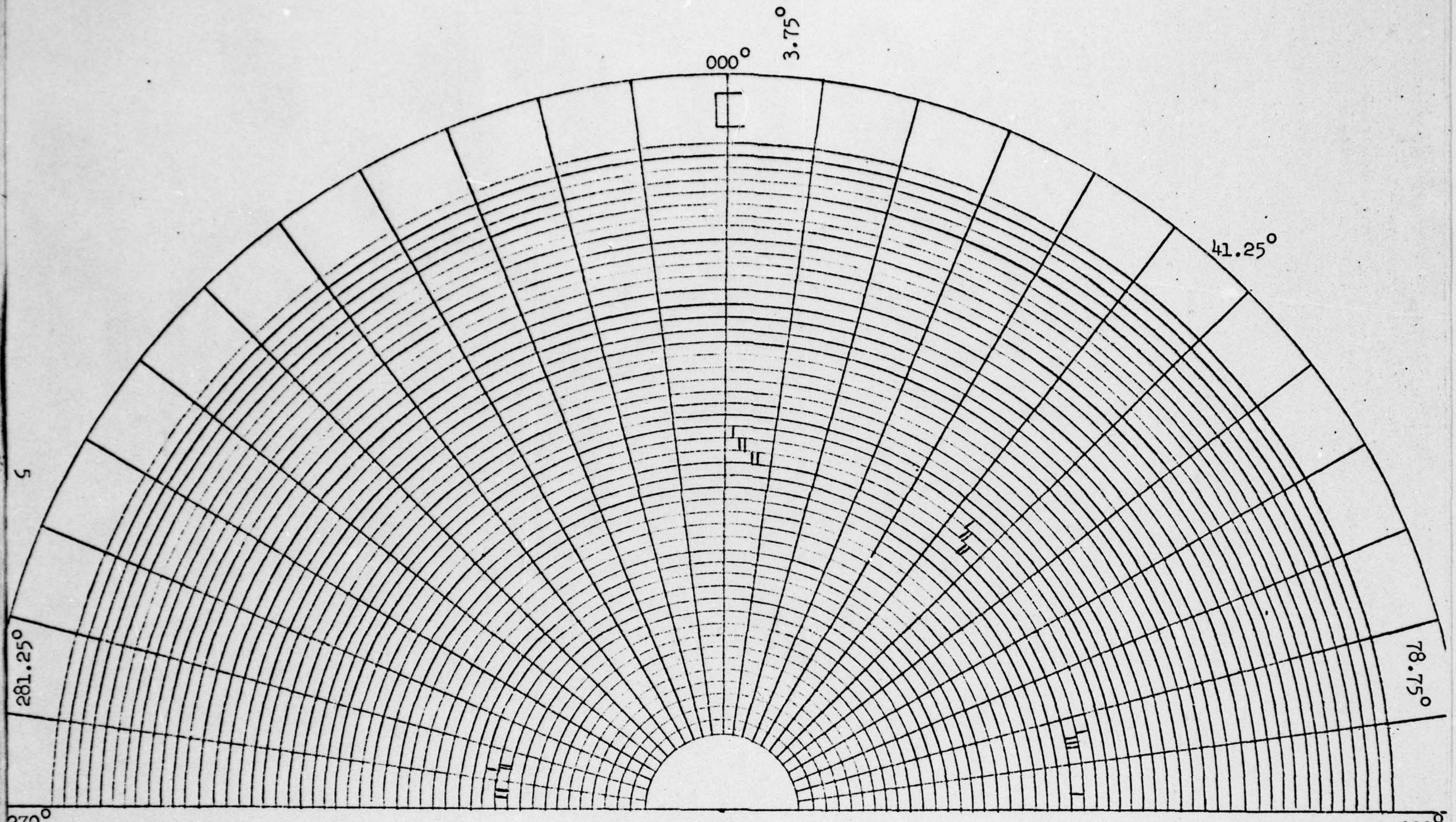
Single Frequency

Echo time per yd. of range = 1.25 ms.

Own ship's speed = 15 kt. = $8\frac{1}{3}$ yd/sec.

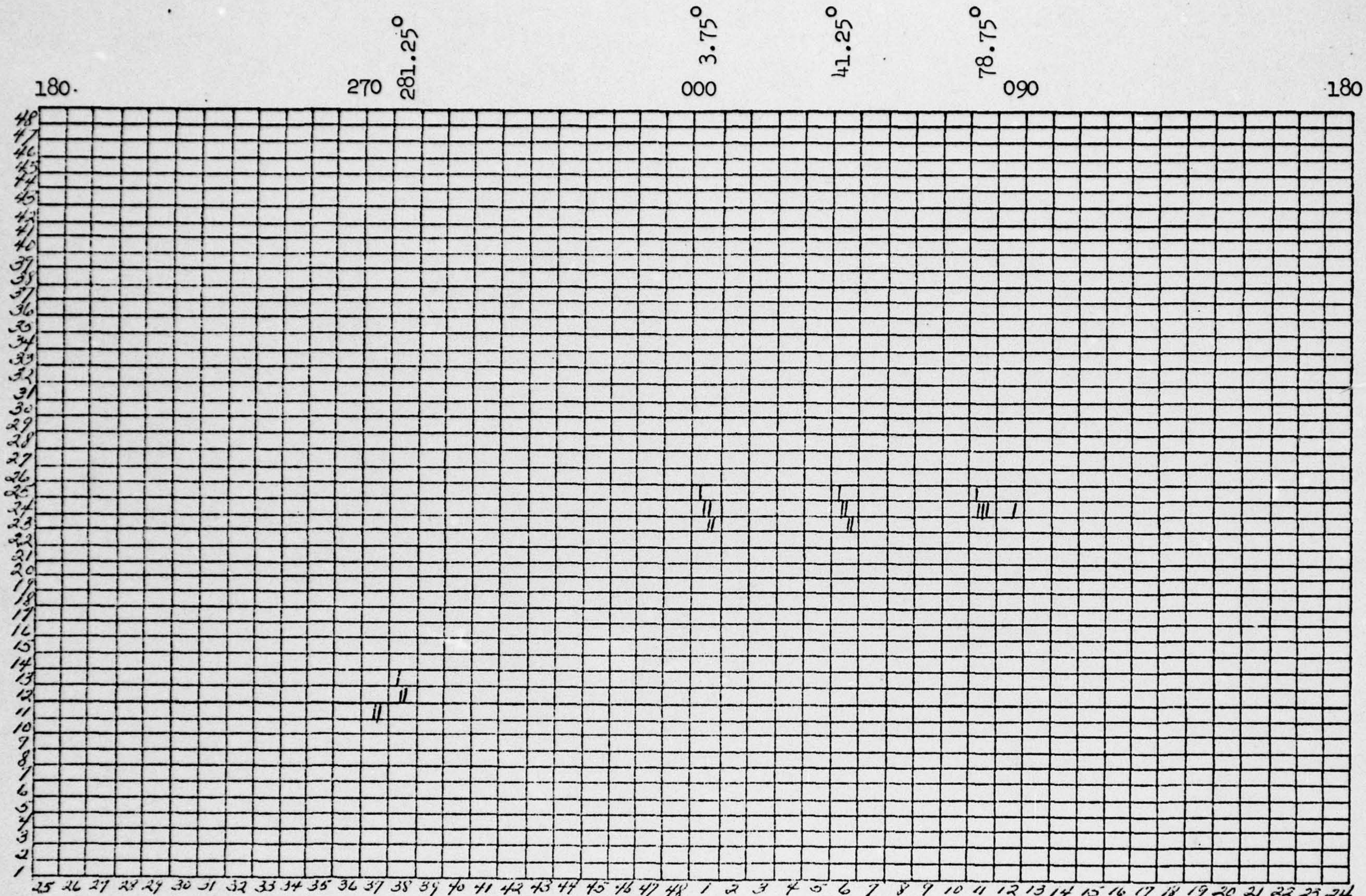
Five period memory display

Search Scale Omni	Search Scale RDT	Track Scale	Trans. Period	Ship's Motion	Range Bin Size	5 Period Spread Range	5 Period Spread Bearing
2.5 Kyd	0	2.5 Kyd	6.25 sec.	52 yd/period	52 yd.	5 bins	3 bins
5 Kyd	0	5 Kyd	12.5 sec.	104 yd/period	104 yd.	5 bins	3 bins
4 Kyd	10 Kyd	2.5 Kyd	46.9 sec.	391 yd/period	208 yd.	9 bins	4 bins
4 Kyd	10 Kyd	5 Kyd	56.3 sec.	469 yd/period	208 yd.	11 bins	5 bins
4 Kyd	20 Kyd	2.5 Kyd	71.9 sec.	599 yd/period	416 yd.	7 bins	3 bins
4 Kyd	20 Kyd	5 Kyd	81.3 sec.	677 yd/period	416 yd.	8 bins	4 bins



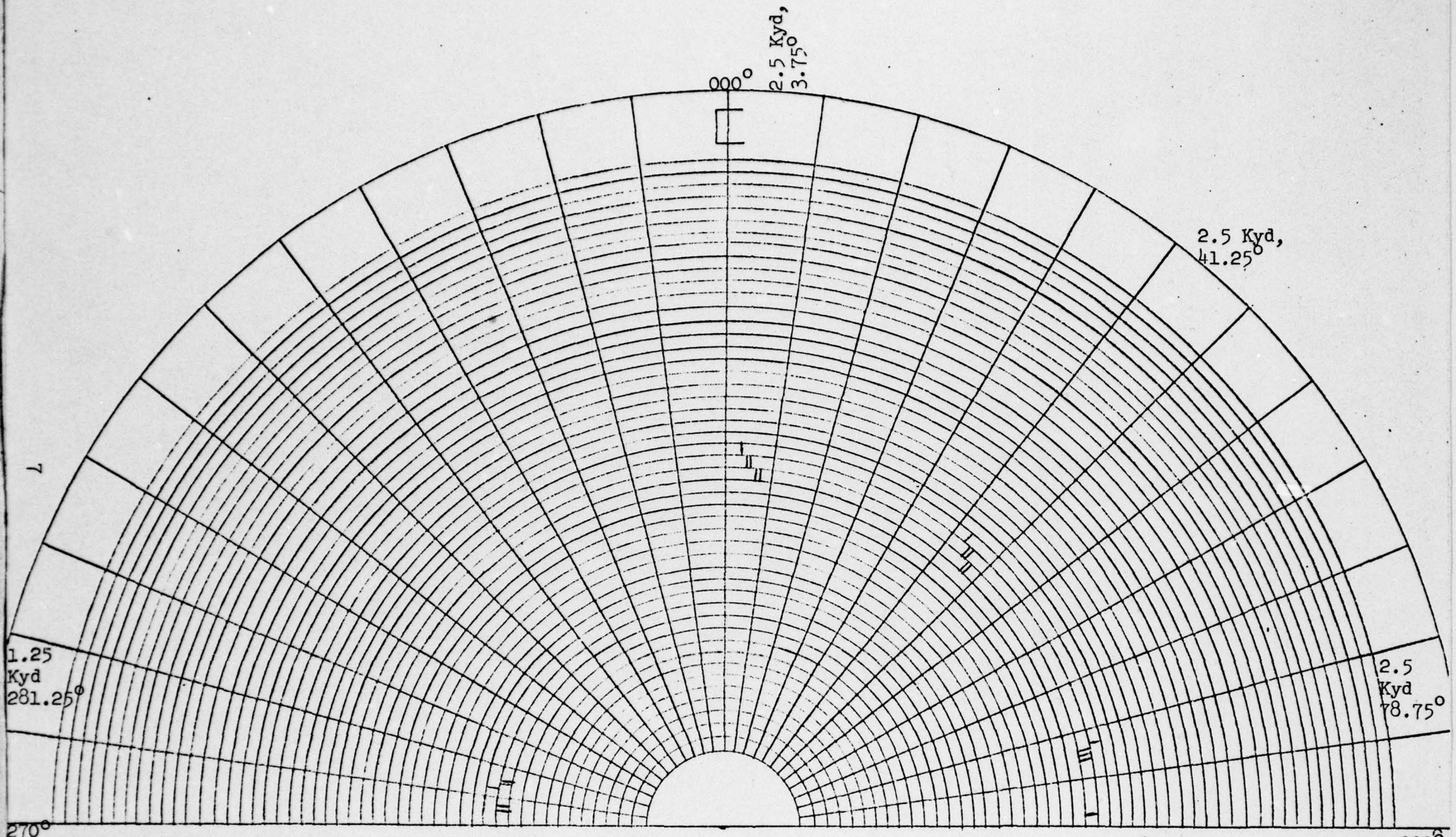
Simple Modes

Ship's Course = 000°
Ship's Speed = 15 kt.
Target Speed = 0 kt.
Range Scale = all
Trans. Period = Fixed by range scale



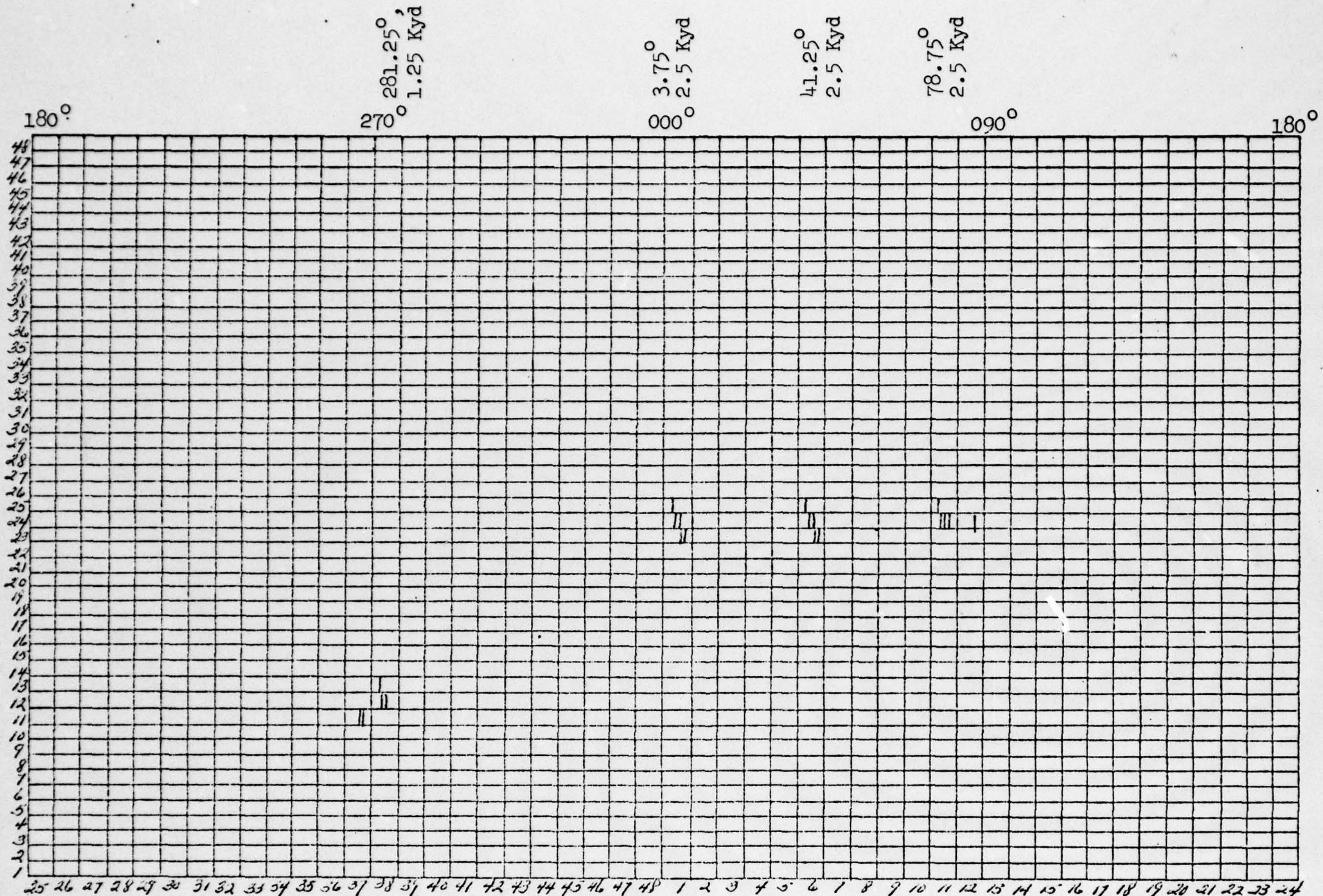
Simple Modes

Ship's Course = 000°
Ship's Speed = 15 kt.
Target Speed = 0 kt.
Range Scale = all
Trans. Period = Fixed by Range Scale



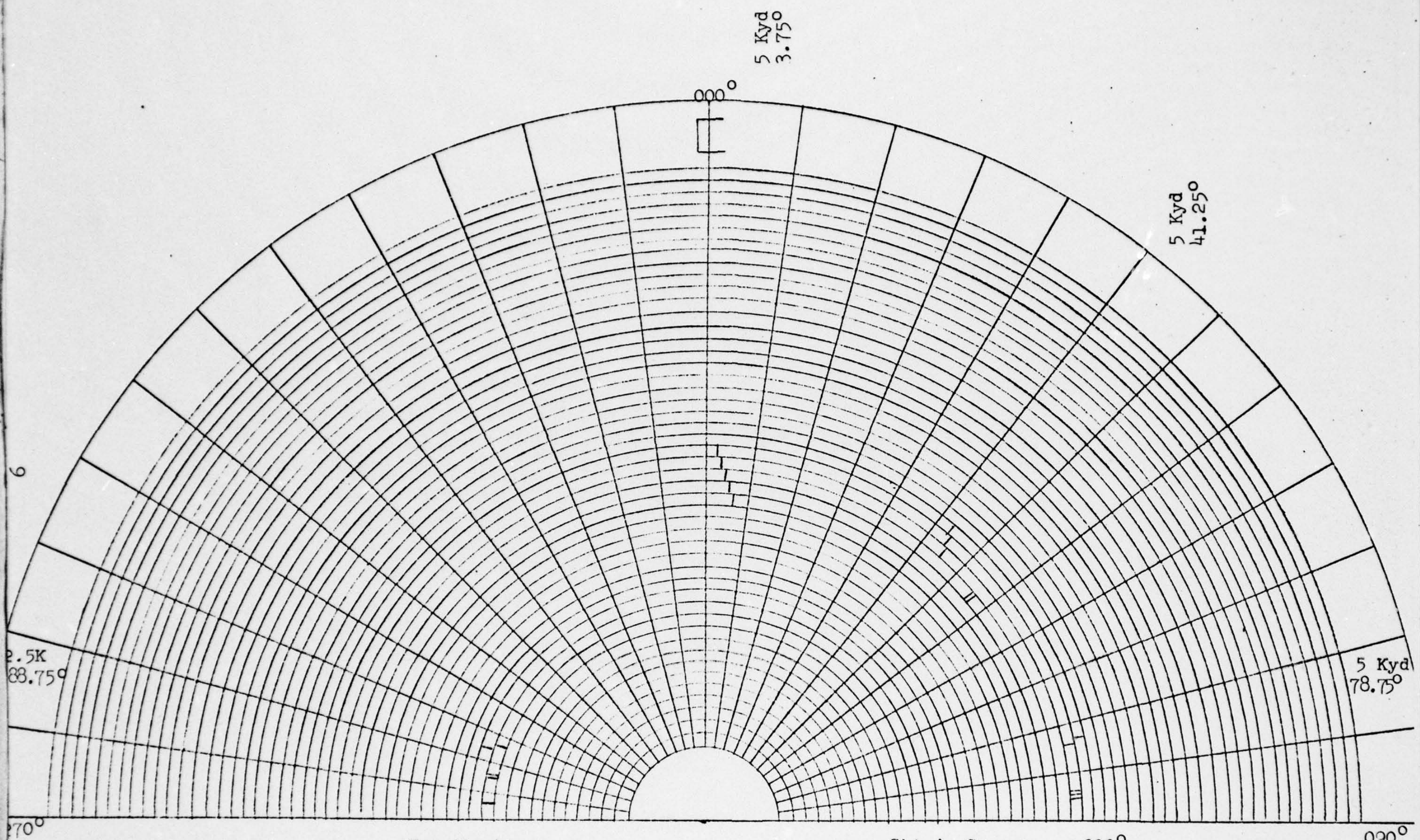
Non-Alerting
Dual Frequency

Ship's Course = 000°
Ship's Speed = 15 kt.
Target Speed = 0 kt.
Range Scale = 5 Kyd
Trans. Period = 6.25 sec.



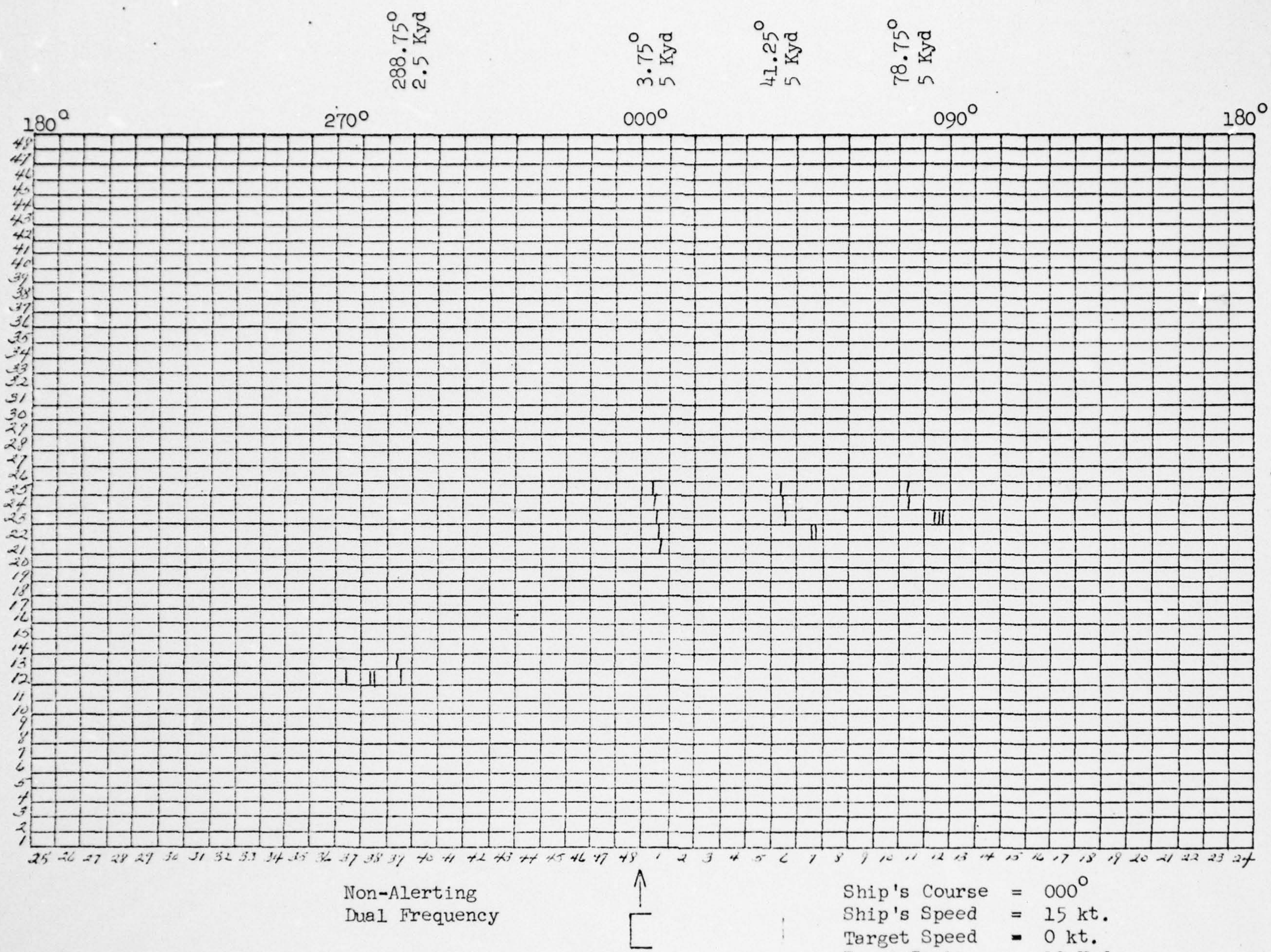
Non-Alerting
Dual Frequency

Ship's Course = 000°
Ship's Speed = 15 kt.
Target Speed = 0 kt.
Range Scale = 5 Kyd
Trans. Period = 6.25 sec.



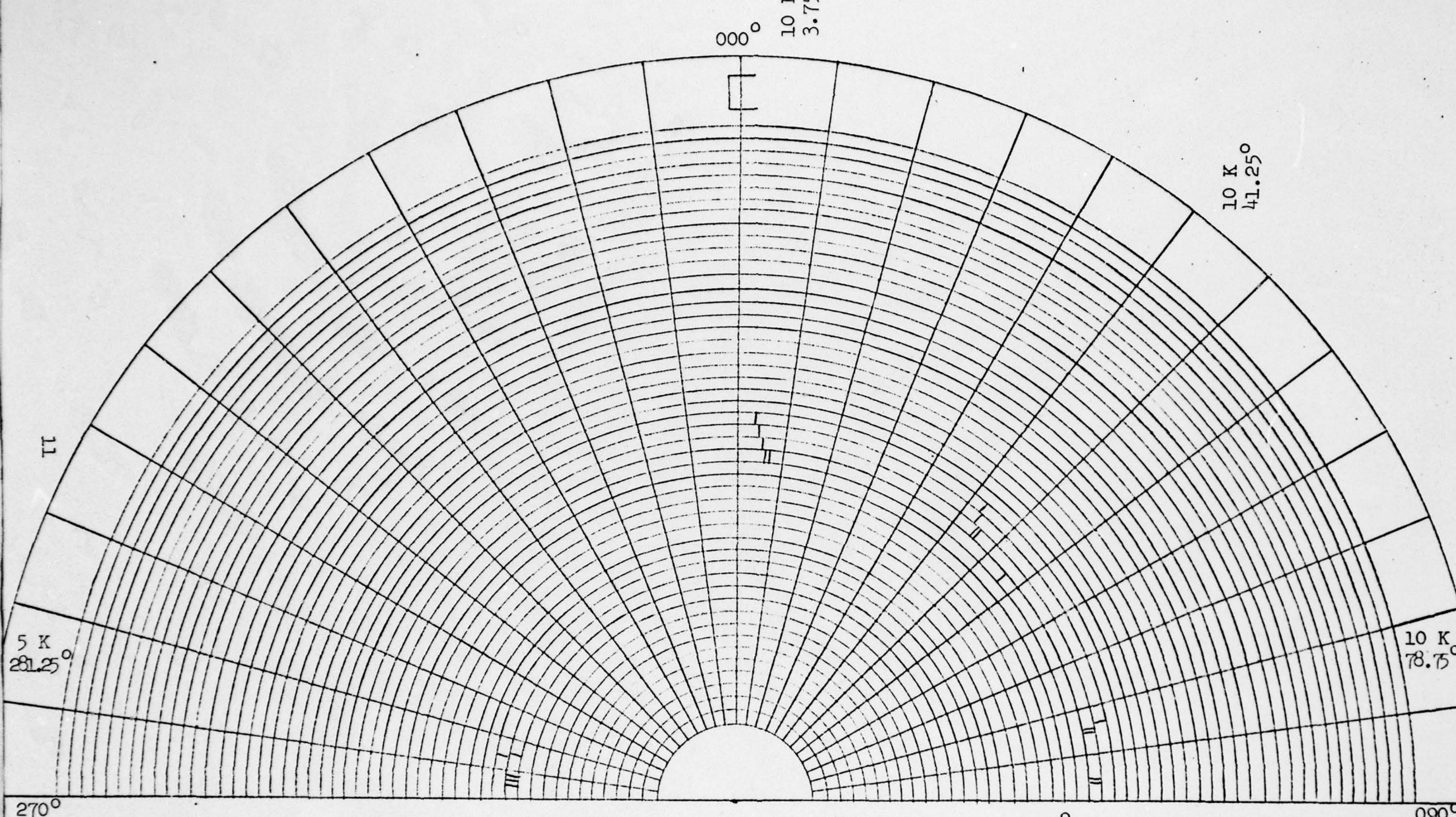
Non-Alerting
Dual Frequency

Ship's Course	=	000°
Ship's Speed	=	15 Kt.
Target Speed	=	0 Kt
Range Scale	=	10 Kyd
Trans, Period	=	25 sec.



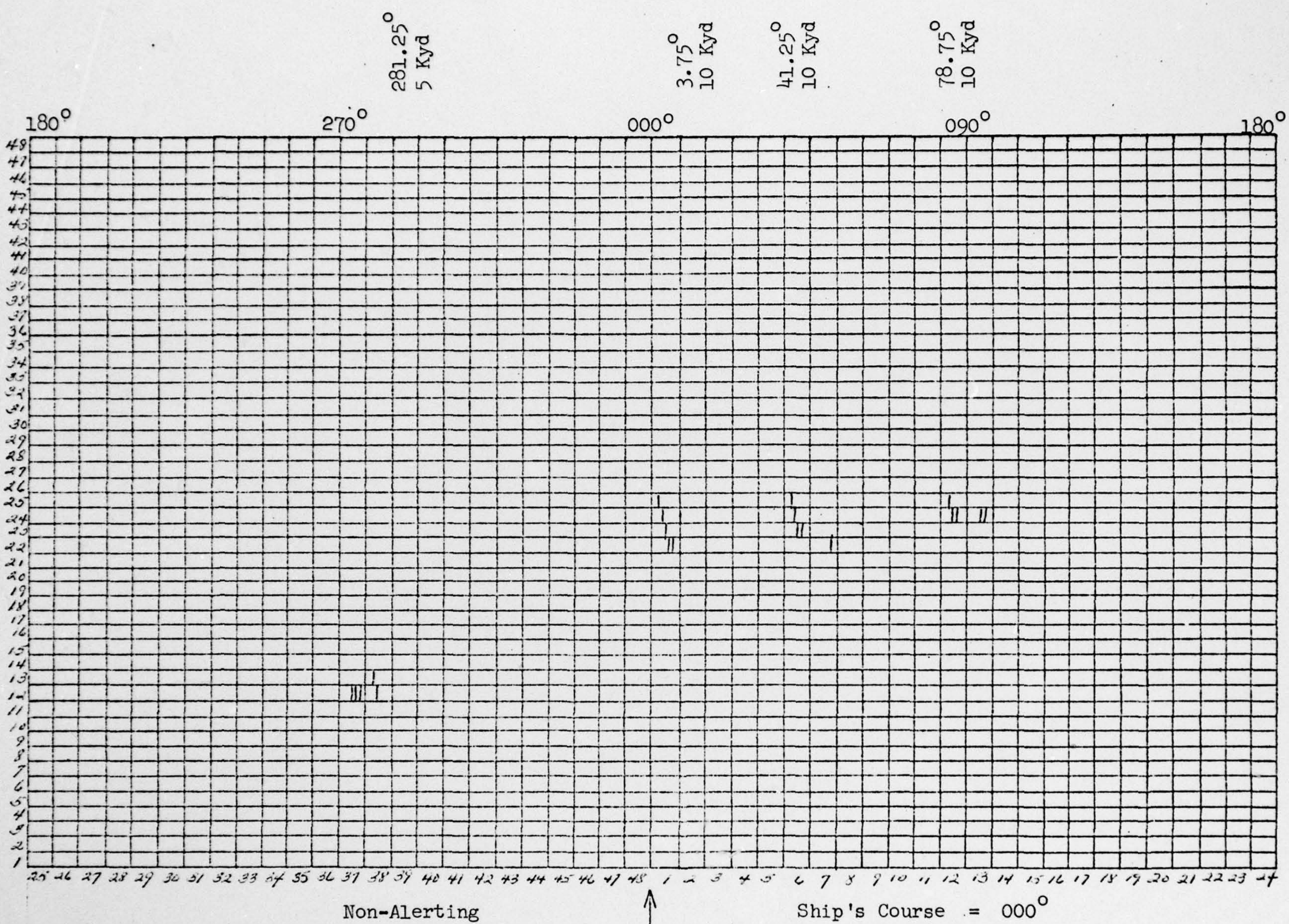
Non-Alerting
Dual Frequency

Ship's Course = 000°
Ship's Speed = 15 kt.
Target Speed = 0 kt.
Range Scale = 10 Kyd
Trans. Period = 25 sec.



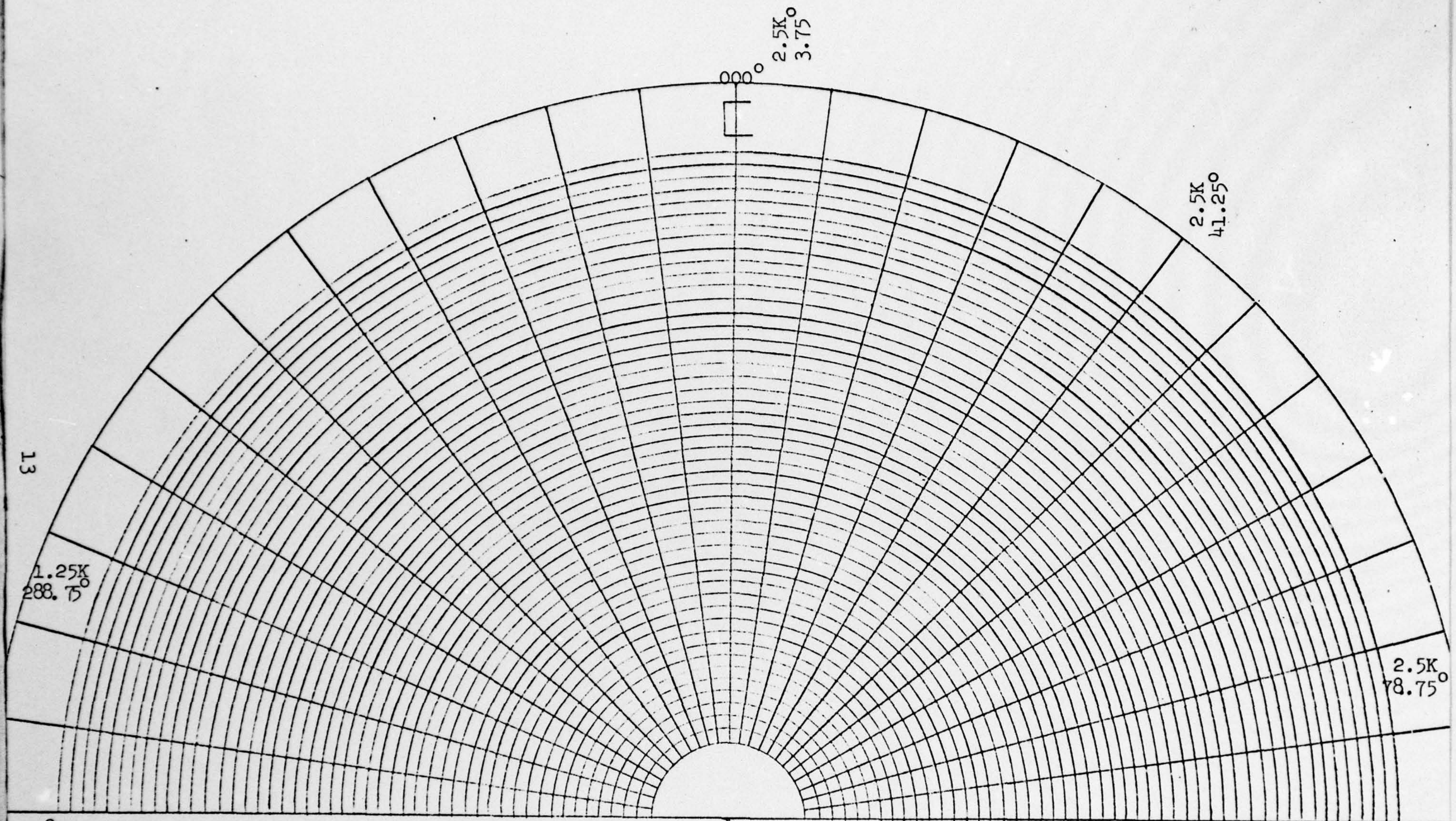
Non-Alerting
Dual Frequency

Ship's Course	=	000°
Ship's Speed	=	15 kt.
Target Speed	=	0 kt.
Range Scale	=	20 Kyd
Trans. Period	=	37.5 sec.



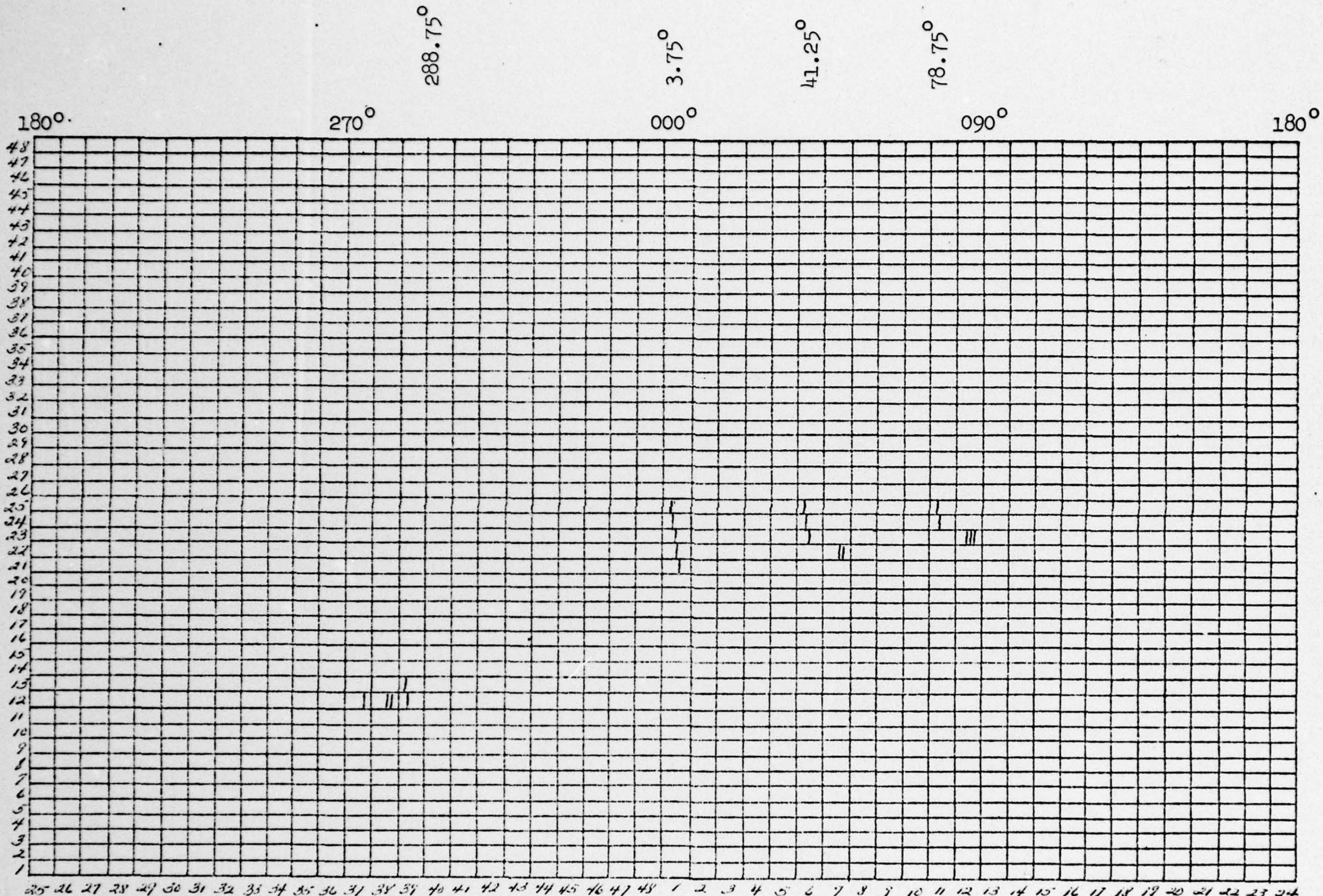
Non-Alerting
Dual Frequency

Ship's Course = 000°
Ship's Speed = 15 kt.
Target Speed = 0 kt.
Range Scale = 20 Kyd
Trans. Period = 37.5 sec.



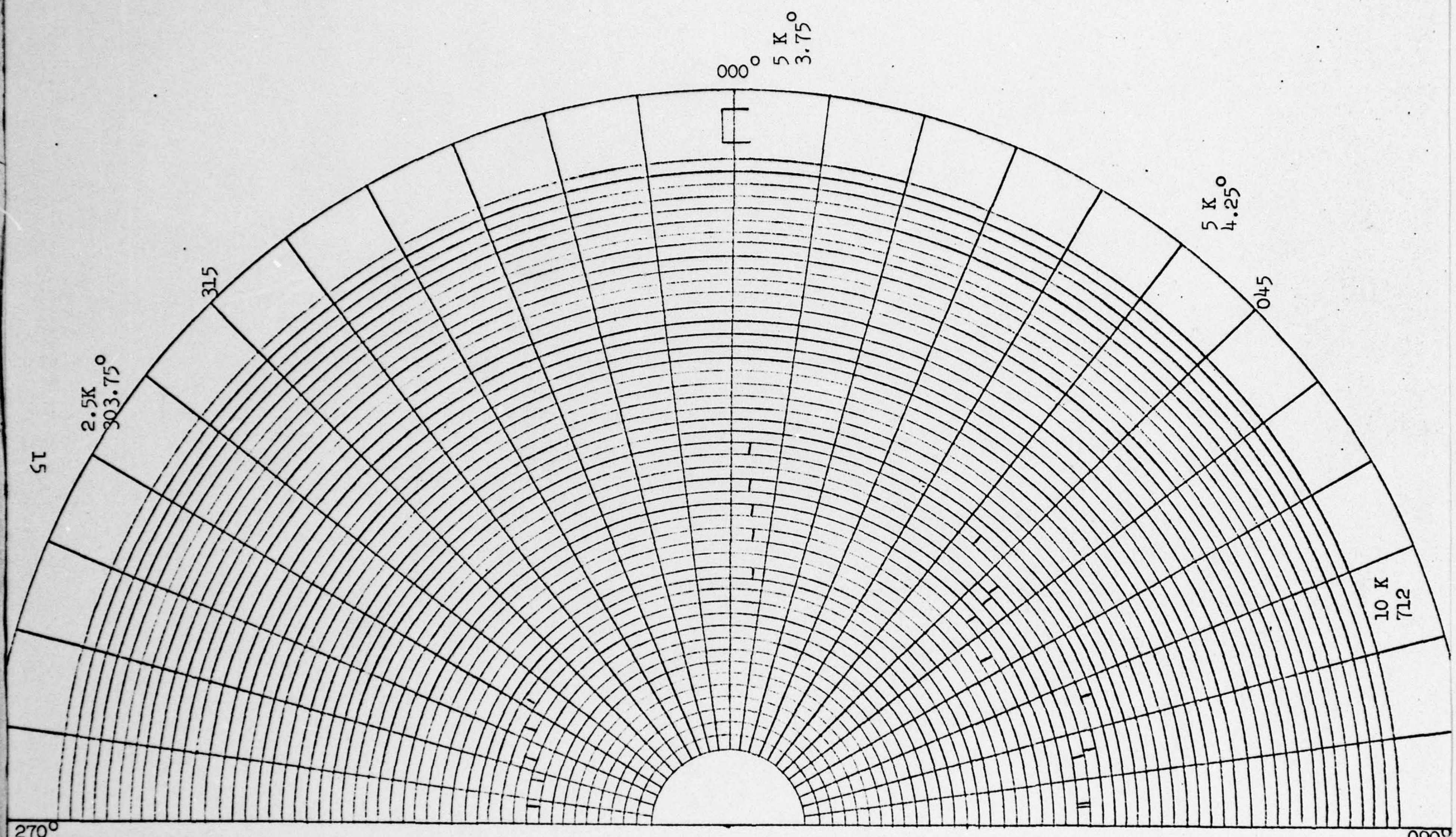
Non-Alerting
Single Frequency

Ship's Course	=	000°
Ship's Speed	=	15 kt.
Target Speed	=	0 kt.
Range Scale	=	5 Kyd
Trans. Period	=	12.5 sec.



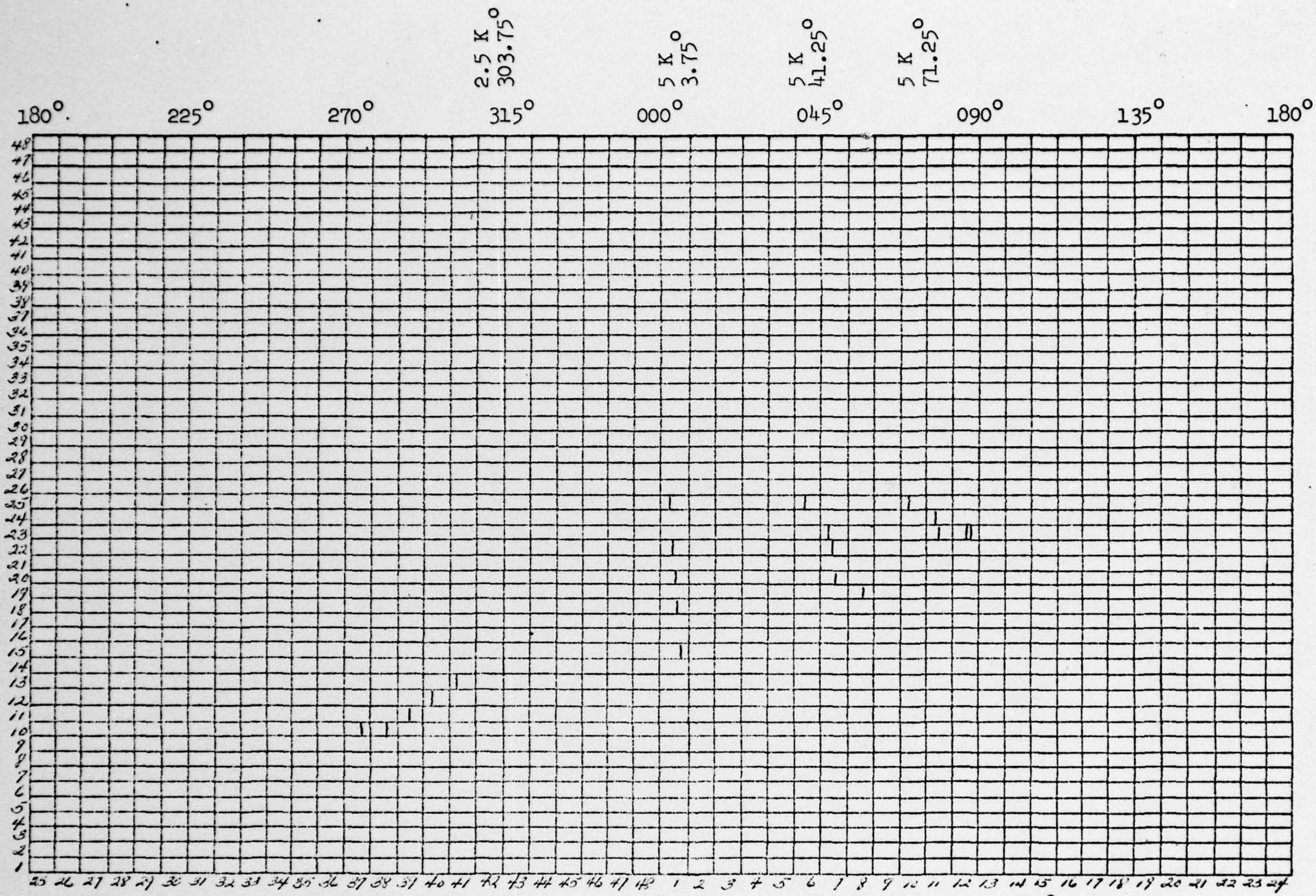
Non-Alerting
Single Frequency

Ship's Course = 000°
Ship's Speed = 15 kt.
Target Speed = 0 kt.
Range Scale = 5 Kyd
Trans. Period = 12.5 sec.



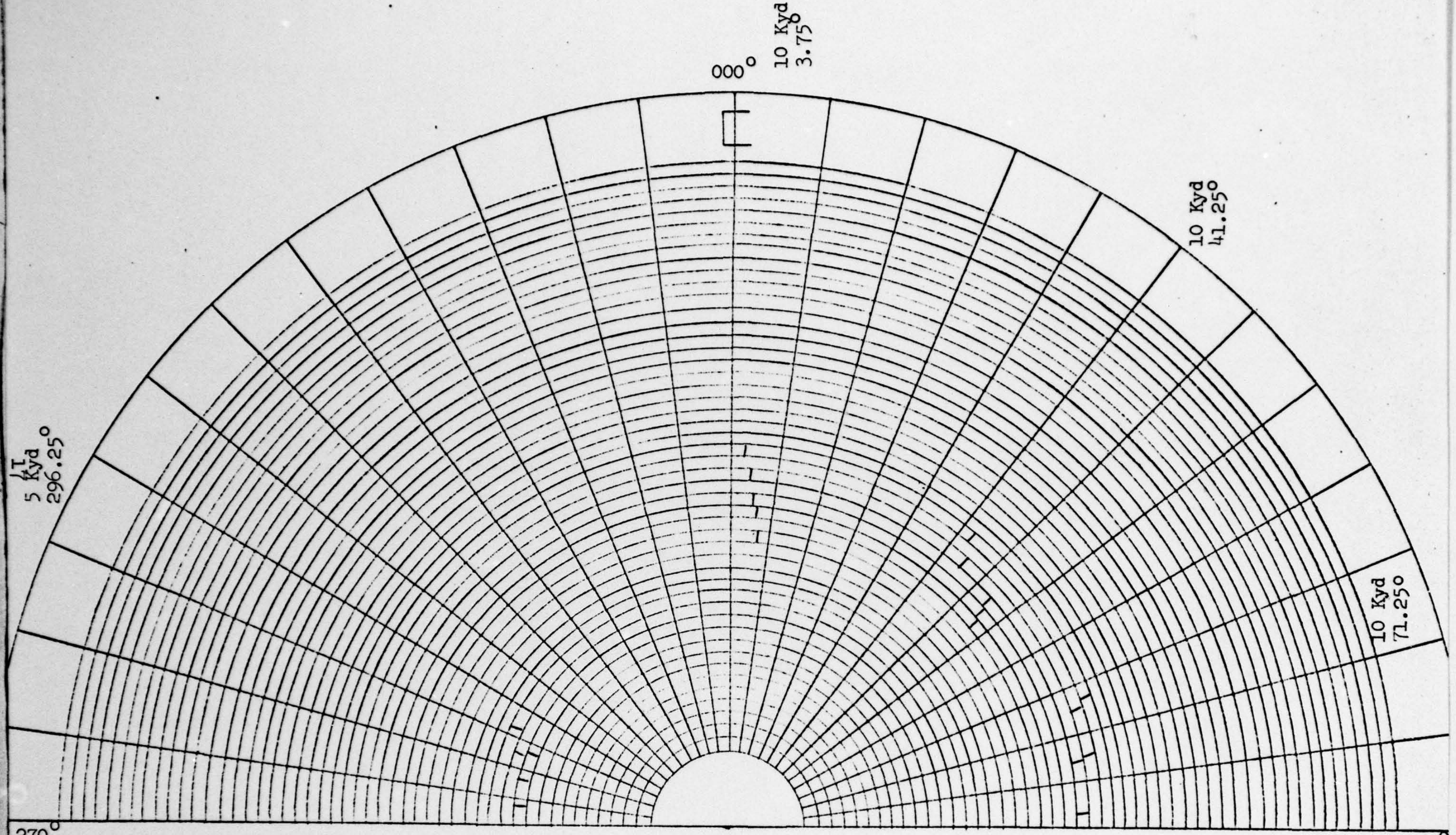
Non-Alerting
Single Frequency

Ship's Course = 000°
Ship's Speed = 15 kt.
Target Speed = 0 Kyd
Range Scale = 10 Kyd
Trans. period = 56.3 sec.



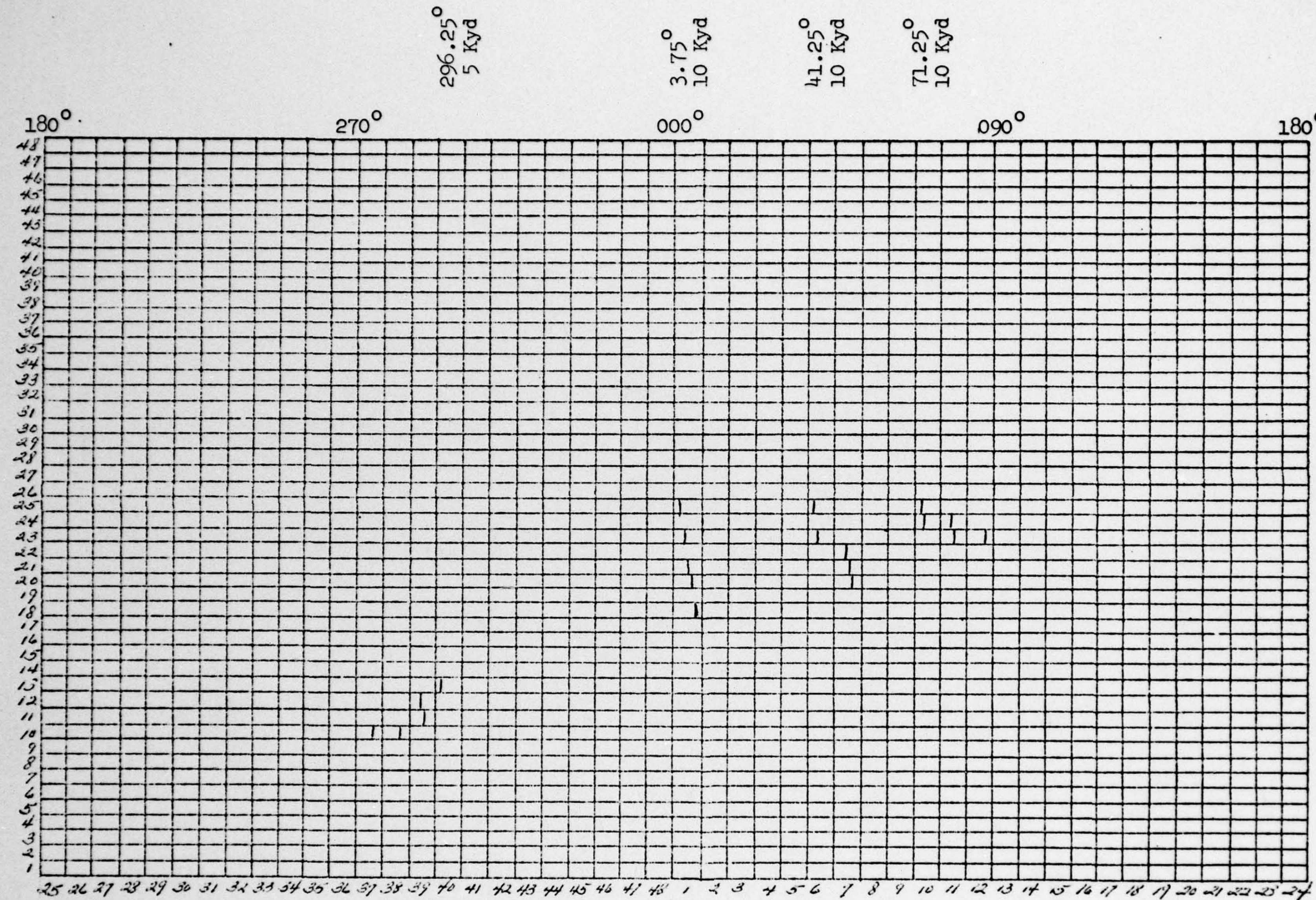
Non - Alerting
Single Frequency

Ship's Course = 000°
Ship's Speed = 15 kt.
Target Speed = 0 kt.
Range Scale = 10 Kyd
Trans. Period = 56.3 sec.



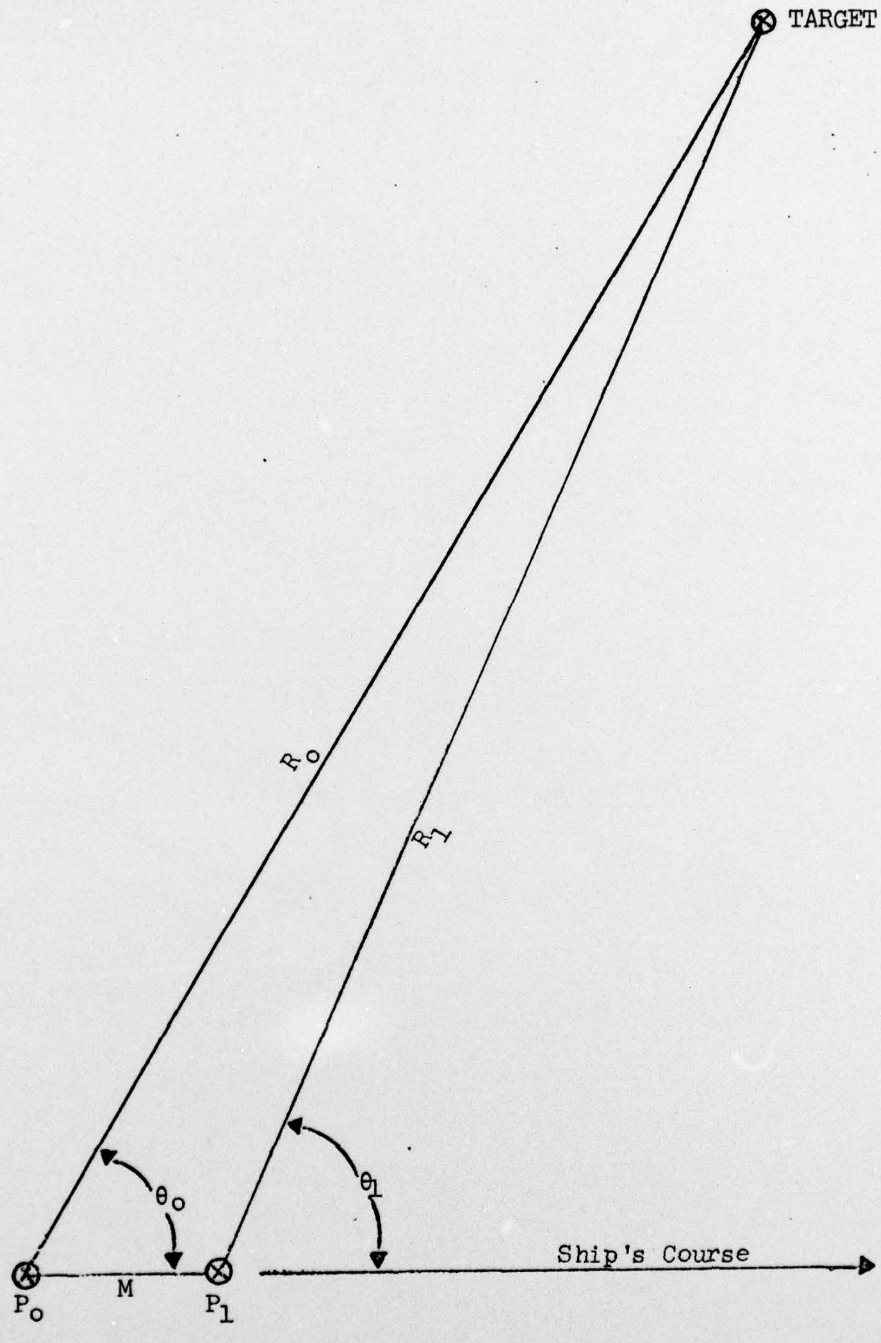
Non-Alerting
Single Frequency

Ship's Course = 000°
Ship's Speed = 15 kt.
Target Speed = 0 kt.
Range Scale = 20 Kyd
Trans. Period = 81.3 sec.



Non-Alerting
Single Frequency

Ship's Course = 000°
Ship's Speed = 15 kt.
Target Speed = 0 kt.
Range Scale = 20 Kyd
Trans. Period = 81.3 sec.


TARGET
R_o
R_1
θ_o
θ_1
Ship's Course
P_o
M
P_1

P_o = Ship position when echo was received

P_1 = Ship position at time of correction

$M = P_1 - P_o$ = Ship's motion over the period being considered

R_o = Target range when echo was received

R_1 = Target range at time of correction

θ_o = Angle between ship's course and target bearing when echo was received

θ_1 = Angle between ship's course and target bearing at time of correction.

θ_o, R_o, P_o, P_1 and M are known

R_1 and θ_1 are to be calculated.

$$R_1 = \sqrt{R_o^2 + M^2 - 2RM \cos\theta_o}$$

$$\theta_1 = 180^\circ - \text{Arc Cos}\frac{R_1^2 + M^2 - R_o^2}{2RM}$$

Both of the above solutions are obtained directly from the law of cosines.

The required values for R_1 and θ_1 are derived to a close approximation when $R_o \gg M$ by the following equations

$$R_1 \text{ approx.} = R_o - M \sin(90^\circ - \theta)$$

$$\theta_1 \text{ approx.} = \theta_o + \text{Arc tan}\left(\frac{M \sin\theta}{R_1}\right).$$

CONCLUSIONS

The amount of information available on the PAIR data processing units is insufficient to form a basis for statements about feasibility or methods of implementing own ship's motion compensation for the search display. It can be surmised that certain operations may be necessary and that the times they occupy in the transmit-receive cycle may depend on computer capability.

It would be more desirable from accuracy considerations to perform the operations continuously. Continuous integration of own-ships' motion would allow calculation and updating of a correction quantity for each beam, and storage in memory for future use. Compensation would be applied to each event word as it was taken from memory to be displayed if own ship's motion since event storage or last compensation were great enough to require correction by one full range or bearing bin.

It is worth noting that it is the old data which is corrected to the position from which the next echo is expected to come, so that the display is always correct and current with respect to own ship's progress through the water.

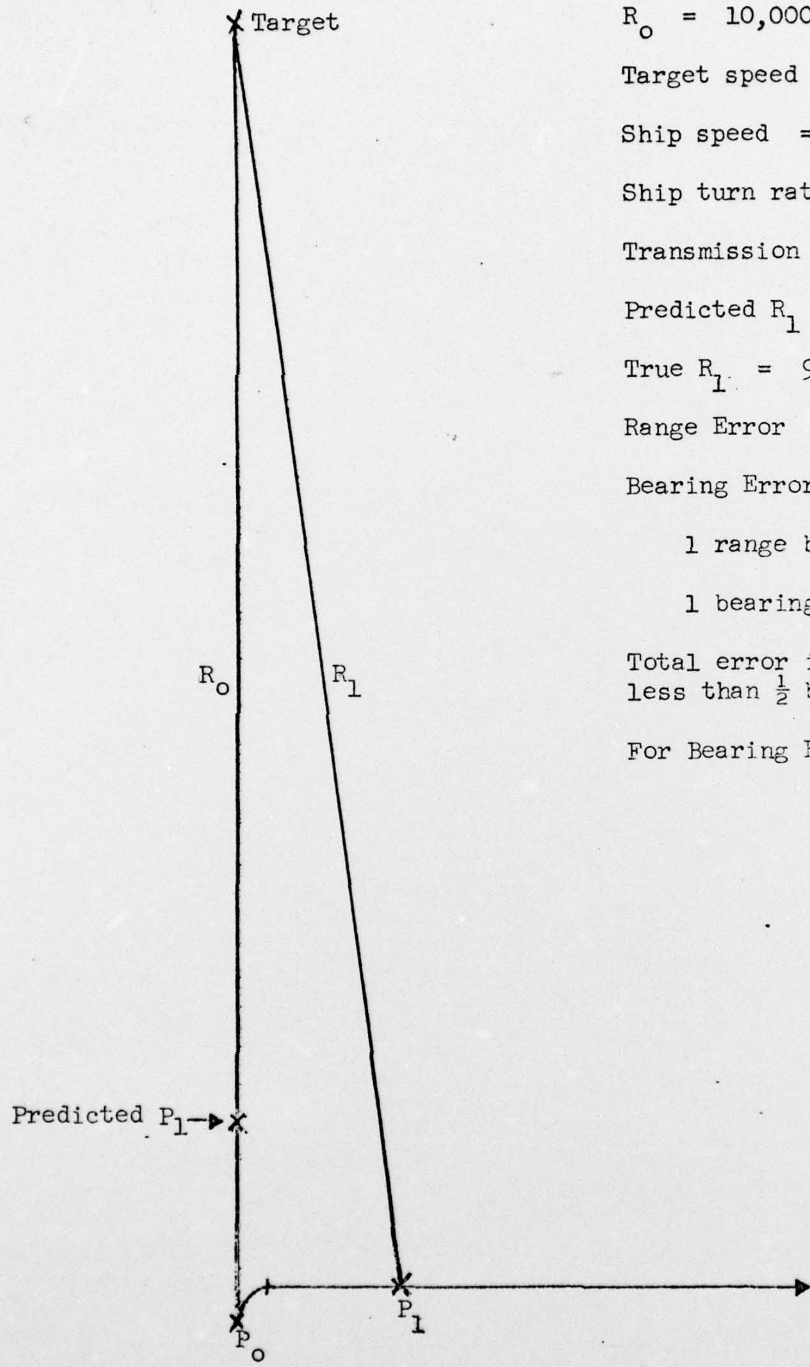
This way of achieving compensation requires that operations be performed while the computer is already busy storing new data and producing old data from storage for display. If the false alarm rate were 20% of the possible 11,520 display positions, about 2300 words would need to be examined per write cycle lasting about 1/30 second. Probably less than 1% of these words would require correction during any one write cycle but the total time involved is considerable.

This form of display compensation should be very satisfactory. Except for the limitations of the water and detection equipment, almost all echoes from a stationary target should appear in a single range-bearing bin. The operator would see about 1/10 of all displayed events move the space of one bin during a full transmit-receive period and these changes would be distributed through the cycle, occurring one or a few at a time.

There is a comparatively idle time lasting from 30 ms to several seconds depending on the type of transmission pulse. It might be possible to accomplish the whole compensation sequence in this period when no new data is being received. Ship's motion since last pulse transmission could be used to calculate the 48 beam correction quantities, and their application to all stored event words requring correction might be completed before pulse transmission is ended. The operator would see the whole display change practically instantaneously.

From an accuracy standpoint this method of compensation has some theoretical deficiencies. Accelerations or course changes by own ship might cause serious inaccuracies with long transmit-receive cycles since ship's motion is calculated from one transmission to the next, while the echo may be received almost a full receive period later than the calculation of correction. This time may amount to as much as 1-1/3 minutes.

Since a display simulation project is being planned; the incorporation of a study of need, feasibility and results to be expected from own ship's motion compensation on the search display may be considered for this simulation.



R_o = 10,000 yd.

Target speed = 0

Ship speed = 15 kt = $8\frac{1}{3}$ yd/sec.

Ship turn rate = 3^o per second

Transmission period = 81.3 sec.

Predicted R_1 = 9,322.5 yd.

True R_1 = 9,858.4 yd.

Range Error = 536 yd

Bearing Error = 3.4^o

1 range bin = 416 yd.

1 bearing bin = $7\frac{1}{2}$ degrees

Total error is about $1\frac{1}{4}$ range bins and less than $\frac{1}{2}$ bearing bin.

For Bearing Error of $7\frac{1}{2}^o$, R_o = 4619 yd.

BATCH UPDATE ERROR

Ship's motion per period $= 81.3 \times 8\frac{1}{3}$ yd $= 677.5$ yd

Time to turn 90° at 3°/sec = 30 sec.

Distance in turn $= 30 \times 8\frac{1}{3}$ yd $= 250$ yd.

Distance after completion of turn $= 677.5 - 250 = 427.5$ yd.

Radius of turn $= \frac{4 \times 250}{2\pi} = 159$ yd.

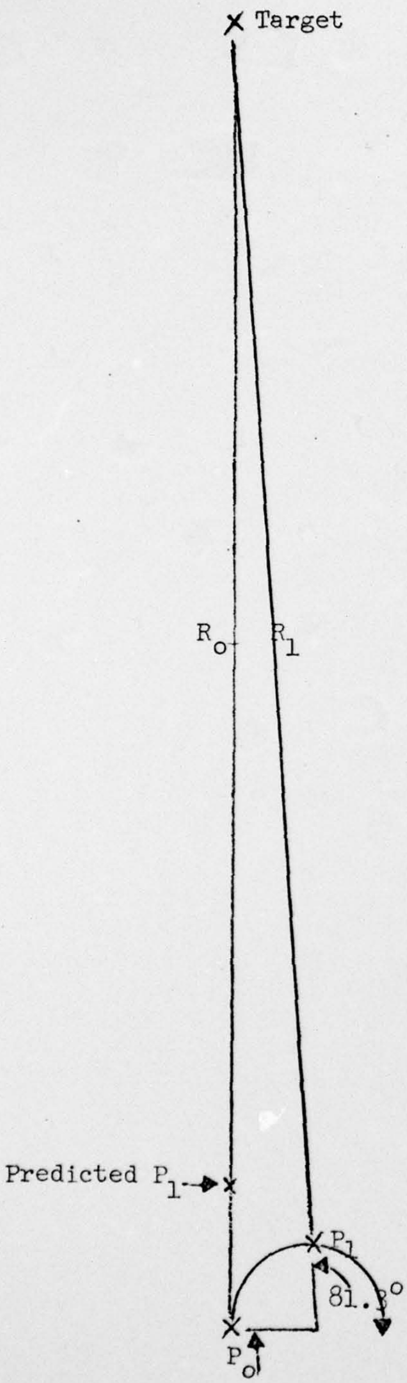
$$R_1 = \sqrt{(10{,}000 - 159)^2 + (159 + 427.5)^2} = 9858.4 \text{ yd.}$$

Bearing error is the difference between true bearings from P_1 and P_1 predicted.

$$E_b = \text{arc sin } \frac{159 + 427.5}{9858.4} = 3.4^\circ$$

For bearing error $= 7\frac{1}{2}^\circ$, -

$$R_o = \frac{159 + 427.5}{\tan 7.5^\circ} + 159 = 4619 \text{ yd.}$$



R_o = 10,000 yd

Target speed = 0

Ship speed = 15 kt = $8\frac{1}{3}$ yd/sec.

Ship turn rate = 1° per sec.

Transmission period = 81.3 sec.

Predicted R_1 = 9322.5 yd.

True R_1 = 9536 yd.

Range error = 213.5 yd

Bearing Error = 2.4°

1 range bin = 416 yd

1 bearing bin = $7\frac{1}{2}^{\circ}$

Total error is about $\frac{1}{2}$ range bin and about 1/3 bearing bin

For Bearing Error of $7\frac{1}{2}^{\circ}$, R_o = 3557 yd.

BATCH UPDATE ERROR

Ship's motion per period $= 81.3 \times 8\frac{1}{3}$ yd $= 677.5$ yd.

Course change at 1°/sec $= 81.3$ sec $\times 1^{\circ}$/sec $= 81.3^{\circ}$

$$\text{Radius of turn} = \frac{360 \times 8\frac{1}{3}}{2\pi} = 477 \text{ yd.}$$

$$R_1 = \sqrt{(10{,}000 - 477 \sin 81.3^{\circ})^2 + (477 - 477 \cos 81.3^{\circ})^2}$$

$$R_1 = 9536 \text{ yd}$$

Bearing Error

$$E_b = \text{arc sin}\ \frac{477 - 477 \cos 81.3^{\circ}}{9536} = 2.4^{\circ}$$

For Bearing Error $= 7\frac{1}{2}^{\circ}$,

$$R_o = \frac{477 - 477 \cos 81.3^{\circ}}{\tan 7.5^{\circ}} + 477 = 3557 \text{ yd.}$$